

PEDESTRIAN TRAVEL-TIME MAPS FOR SITKA, ALASKA: An anisotropic model to support tsunami evacuation planning

by

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ABSTRACT

Tsunami-induced pedestrian evacuation for Sitka is evaluated using an anisotropic modeling approach developed by the U.S. Geological Survey. The method is based on path-distance algorithms and accounts for variations in land cover and directionality in the slope of terrain. We model evacuation of pedestrians to exit points from the tsunami hazard zone. The pedestrian travel is restricted to the roads only. Results presented here are intended to provide guidance to local emergency management agencies for tsunami inundation assessment, evacuation planning, and public education to mitigate future tsunami hazards.



Sitka waterfront. Photo from visitsitka.com.

DISCLAIMER: The developed pedestrian travel-time maps have been completed using the best information available and are believed to be accurate; however, their preparation required many assumptions. Actual conditions during a tsunami may vary from those assumed, so the accuracy cannot be guaranteed. Areas inundated will depend on specifics of the earthquake, any earthquake-triggered landslides, on-land construction, tide level, local ground subsidence, and may differ from the areas shown on the map. Information on this map is intended to permit state and local agencies to plan emergency evacuation and tsunami response actions.

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INTRODUCTION

Subduction of the Pacific plate under the North American plate has resulted in numerous great earthquakes and has the highest potential to generate tsunamis in Alaska (Dunbar and Weaver, 2015). The Alaska–Aleutian subduction zone (figure 1), the fault formed by the Pacific–North American plate interface, is the most seismically active tsunamigenic fault zone in the U.S. Plate motions along the Queen Charlotte–Fairweather Fault System (a transform fault system that runs along the entire southeastern Alaska coastline) has ruptured in numerous high magnitude events. Refer to Suleimani and others (2013) for an overview of the tsunami hazard in the Sitka area.

The most recent earthquake that triggered a significant tsunami in Sitka occurred on March 27, 1964; for this event, tsunami waves were as high as 2.4 m (8 ft) (Lander, 1996). An in-depth analysis of the tsunami hazard in Sitka and estimation of the tsunami hazard zone in the community is provided by Suleimani and others (2013).

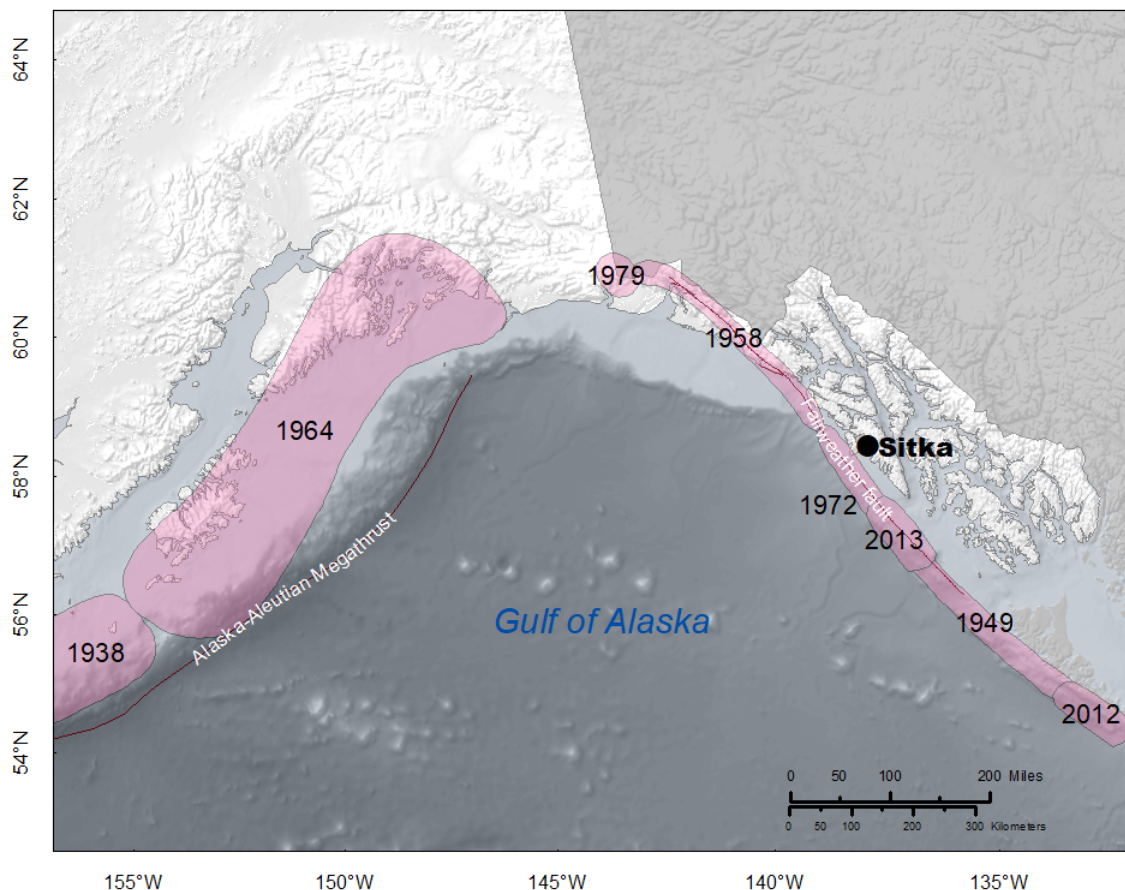


Figure 1: Map of south-central Alaska, showing the location of Sitka and the rupture zones of the 1964 Aleutian subduction zone earthquake and major earthquakes along the Queen Charlotte–Fairweather Fault System (shaded area).

In this report, we employ the pedestrian evacuation modeling tools developed by the U.S. Geological Survey (USGS) (Wood and Schmidlein, 2012, 2013; Jones and others, 2014) to provide guidance to emergency managers and community planners in assessing the amount of time required for people to evacuate out of the tsunami-hazard zone. An overview of the pedestrian evacuation modeling tools, required datasets, and the step-by-step procedure used is provided in Macpherson and others (2017, this series). The maps of pedestrian travel time can help identify areas in Sitka on which to focus evacuation training and tsunami education.

COMMUNITY PROFILE

The city of Sitka (57°3'N, 135°20'W) on the west coast of Baranof Island in southeast Alaska was the original capital of Russian Alaska. Sitka is home to approximately 4,000 households, more than 8,500 people (U.S. Census Bureau) and is only accessible by boat or plane. According to the Alaska Division of Community Advocacy (2011) database, the Borough of Sitka is known for resource extraction including fishing, mining and lumber. Cruise ships bring more than 120,000 people to Sitka annually (Sitka, 2012-2013).

Due to its remote location, limited access, low-lying population center and high influx of seasonal tourists, the potential impact of a tsunami event on the economy and infrastructure is high.

TSUNAMI HAZARD

Tsunami hazard assessment for Sitka was performed by numerically modeling several hypothetical scenarios (Suleimani and others, 2013). The worst-case scenarios for Sitka are thought to be a shallow slip thrust earthquakes beneath Prince William Sound.

Suleimani and others (2013) estimate that several low-lying areas of Sitka can experience flooding with a maximum wave height up to 4.5 m (15 ft). Modeled extents of potential inundation in central Sitka and the airport (Japonski Island) computed by Suleimani and others (2013) is shown in figure 2. See Map Sheet 1 for a larger copy and Map Sheets 2-4 for the extents in the north, west and south.

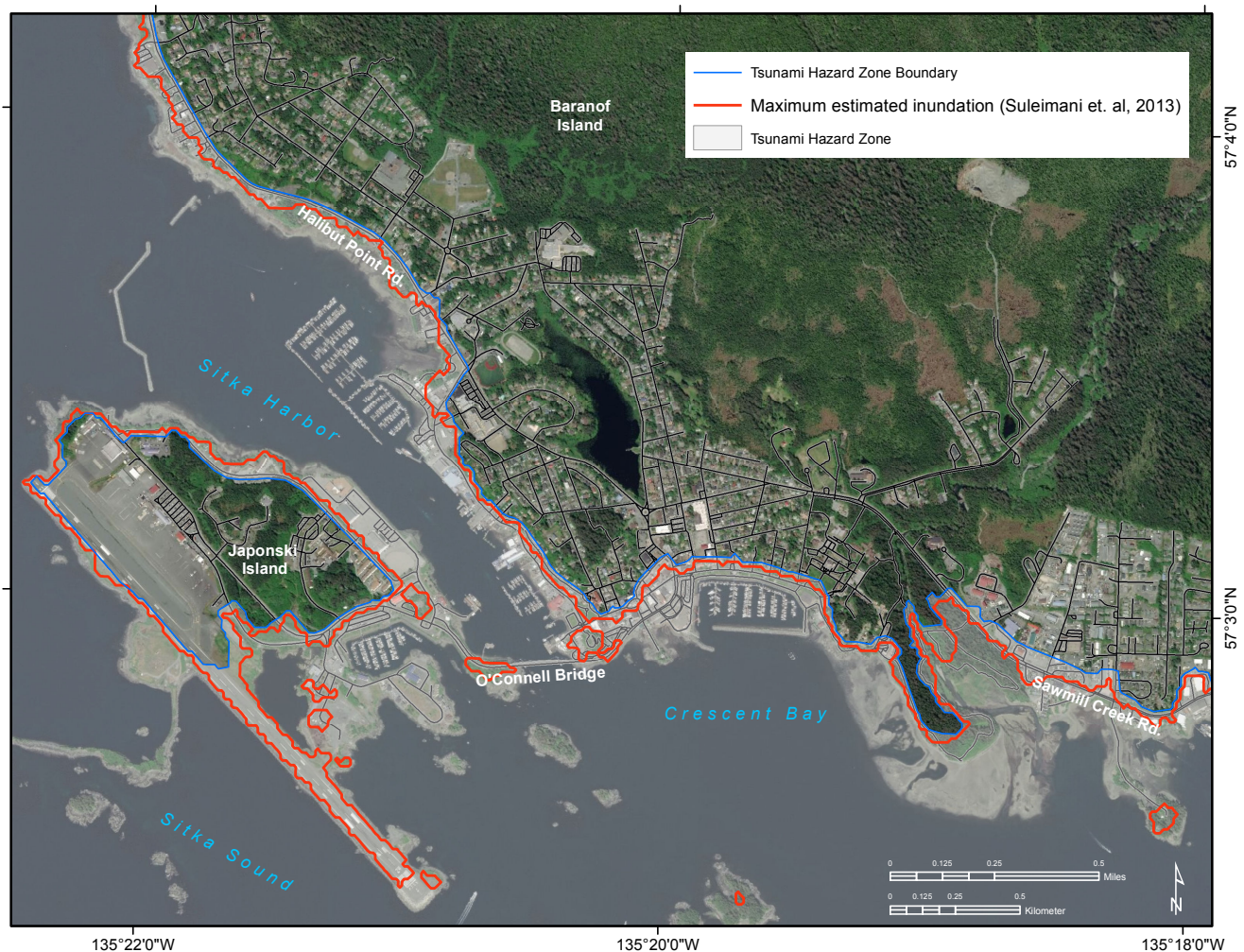


Figure 2: Map of central Sitka and Japonski Island depicting modeled extent of the potential inundation (red line) and the tsunami hazard zone based on the 10% increase in the tsunami runup (blue line).

The hydrodynamic model used to calculate propagation and runup of tsunami waves (Nicolisky and others, 2011) has passed the appropriate validation and verification tests (Synolakis and others, 2007; NTHMP, 2012). Although the developed algorithm has met the benchmarking procedures, there is still uncertainty in locating an inundation line. Refer to Suleimani and others (2013) for an in-depth discussion of the uncertainty in the modeled tsunami hazard zone. For example, the accuracy is affected by many factors including suitability of the earthquake source model, accuracy of the bathymetric and topographic data, and the adequacy of the numerical model in representing the generation, propagation, and runup of tsunamis.

To account for the above-mentioned uncertainties, we enlarge the modeled extent of potential inundation by adding a safety buffer. In particular, areas within 45 m (150 ft) of the inundation line and with the elevations less than 110% of the local runup are thought to be at risk of flooding in the worst-case tsunami event. The potential inundation extent together with the safety buffer is to be called the tsunami hazard zone. Figure 2 shows the tsunami hazard zone boundary, based on the 10% increase in the tsunami runup, in central Sitka and Japonski Island areas.

Upon presentation of the preliminary modeling results at the meeting with emergency managers in Sitka (November 19, 2019), it was decided to enlarge the tsunami hazard zone at least to be consistent with the 25-ft elevation contour above the MHHW tide level¹. Figure 3 shows the tsunami hazard zone boundary, based on the 25-ft elevation contour, in central Sitka and Japonski Island areas, also see Map Sheet 1 for a large copy. Map Sheets 2-4 show the tsunami hazard zone boundary extents in the north, west and south



Figure 3: Map of central Sitka and Japonski Island depicting modeled extent of the potential inundation (red line) and the tsunami hazard zone based on the 25-ft elevation contour (blue line).

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¹ It should be noted that no final decision to draw the tsunami evacuation line along the 25-ft elevation contour was taken at the November 2019 meeting. Please consult with the local emergency coordinators regarding the city-adopted evacuation line for the tsunami hazard.

Sitka. This tsunami hazard zone line based on the 25-ft elevation contour will be used in modeling the pedestrian evacuation as follows.

PEDESTRIAN EVACUATION MODELING

Pedestrian evacuation modeling and prediction of population vulnerability to tsunami hazards were successfully applied to coastal communities in Alaska by Wood and Peters (2015). Also refer to Wood and Schmidtlein (2012, 2013) for an overview and limitations of the anisotropic, least-cost distance (LCD) approach to modeling pedestrian evacuation. We stress that the LCD focuses on the evacuation landscape, using characteristics such as elevation, slope, and land cover to calculate the most efficient path to safety. Therefore, computed travel times are based on optimal routes, and actual travel times may be greater depending on individual route choice and environmental conditions during an evacuation.

Recently, Jones and others (2014) developed the Pedestrian Evacuation Analyst Extension (PEAE) for ArcGIS, which facilitates development of pedestrian travel-time maps. A brief overview of the PEAE and a step-by-step procedure to compute the pedestrian travel-time maps for Alaska coastal communities are provided in Macpherson and others (2017, this series). Note that the data required for the PEAE include: either the tsunami hazard zone or exit points, digital elevation model (DEM) of the community, and land-cover datasets. In the following sections we describe datasets required to compute the travel-time maps, considered scenarios, and modeling results.

DATA COMPILATION AND SOURCES

The following section details the datasets that were obtained and/or created for the community to be used as input for the PEAE. In all cases we used the maximum composite tsunami hazard zone instead of a specific tectonic scenario. All datasets and layers were projected to NAD83 Alaska State Plane Zone 1 m to allow us to compute the final evacuation times in minutes. The original sources of data are summarized in Table 1.

- **Digital Elevation Model:** The DEM employed in this study is consistent with the tsunami DEM used by Suleimani and others (2013) to compute the tsunami inundation. The original source for topographic elevations is the National Geophysical Data Center (NOAA), with a spatial resolution of about 15× 16 m (49 x 54 ft). Note that the tsunami DEM was re-sampled using the PEAE tool to set the analysis cell size at 3 m (10 ft) resolution to improve the accuracy of the travel-time maps.
- **Land Cover:** Roads and trails were added from the OpenStreetMap API (OSM, 2015) and confirmed using high-resolution imagery from the Digital Globe Imagery provided by ESRI. Only the constructed and well-maintained roads are used in the computations.

Table 1. Data sources of the input layers required for the Pedestrian Evacuation Analyst Extension.

Layer in PEAE	Data Sources
Tsunami Inundation Extent	Nicolsky and others (2014)
Exit points	Located on the roads leading from the buffered inundation extent.
DEM	Hickman and others (2012)
Land Cover	Digital Globe imagery
Roads	OpenStreetMap, expanded using Digital Globe Imagery
Imagery	Digital Globe imagery

EVACUATION SCENARIOS

The pedestrian evacuation times are computed for a single scenario² wherein evacuees are thought to leave the tsunami hazard zone on foot and walk toward its boundary. We note that in the case of severe weather conditions or a thick snow cover, the evacuation might be confined to well-traveled roads and paths. Therefore, it is assumed that pedestrians will travel to the closest road and then stay on roads to leave the tsunami hazard zone. Individuals are also assumed to travel in the most optimal way. The latter requires tsunami evacuation signage along the roads in order to exit the tsunami hazard boundary.

The assumed base speed of the evacuee in the scenario is set according to the “slow walk” option (0.91 m/s, 3 ft/s, or 2 mph) in the PEA settings. Note that this is a conservative speed and many residents would be able to evacuate faster (1.52m/s “fast walk”, if not 1.79m/s “slow run”) than the modeled rate. However, soil liquefaction, darkness, freezing rain, ice and/or snow on the road can also significantly impact the walking pace of evacuees.

MODELING RESULTS

We apply the methodology outlined in Macpherson and others (2017, this series) to compute the travel times according to the considered scenarios. The pedestrian travel-time map for central Sitka and Japonski Island are shown in figure 3 (see also Map Sheet 5 for a larger copy). Modeling results for north, west and south Sitka are shown in Map Sheets 6-8.

Modeling results reveal that evacuees could reach safety on Japonski Island, typically, in less than 25 minutes with the longest times (about 40 minutes) at the airport runway and marina. Evacuees would require guidance to remain on the island. Clear signage or educational efforts are required to inform the public regarding the location of the hazard zone boundary. If a complete evacuation by foot of Japonski Island is required, modeling results (not included in this report) indicate that it would take upwards of 90 minutes for evacuees to cross the O’Connell Bridge. Should the bridge become compromised during strong shaking, evacuation would be hindered.

In other areas of Sitka, including north Sitka at the furthest extent of Halibut Point Rd., evacuees could reach the tsunami hazard zone boundary in about 25 minutes (see Map Sheet 6). Similarly, in southern Sitka (Map sheet 8) at points along Sawmill

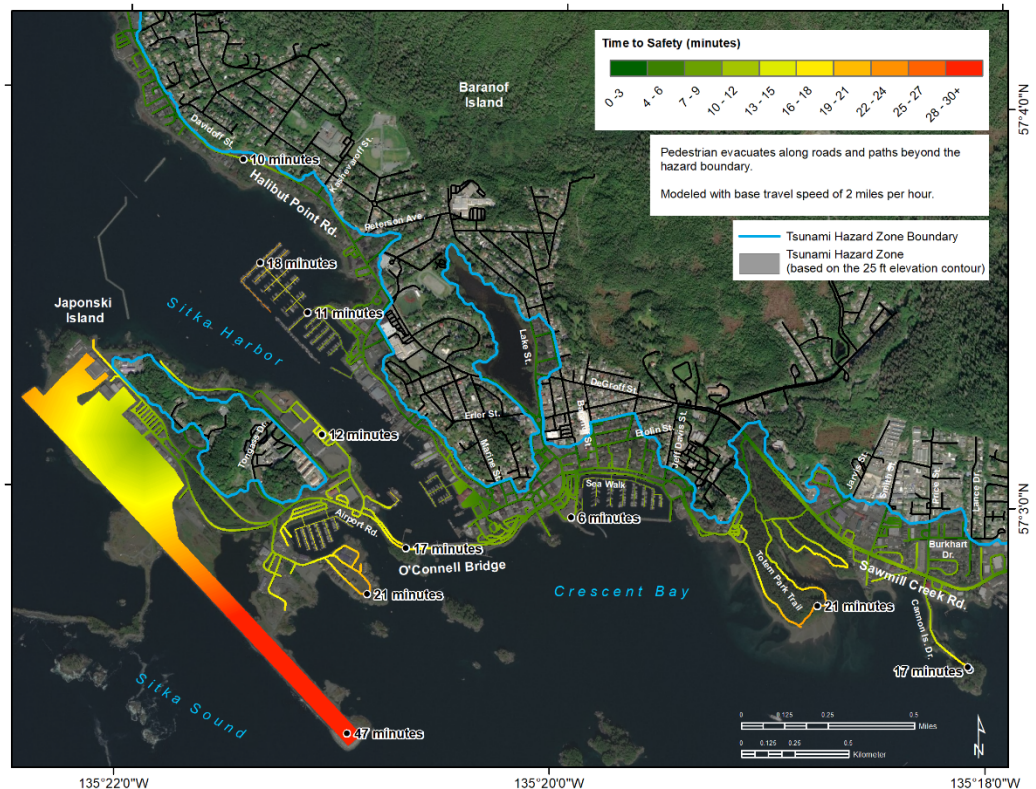


Figure 3: Travel time map for the pedestrian evacuation for central Sitka and Japonski Island beyond the tsunami hazard zone shown by the blue line. Color gradation indicates how many minutes it would take for an evacuee to walk to the nearest exit point.

² Additional scenarios could be considered and added based on the community feedback.

Creek Rd., evacuees would face evacuation times over 25 minutes. Evacuees would need prior education and/or proper signage directing them to the shortest evacuation route.

SOURCES OF ERRORS AND UNCERTAINTIES

The modeling approach described in this report will not exactly represent an actual evacuation; like all evacuation models, the LCD approach cannot fully capture all aspects of individual behavior and mobility (Wood and Schmidlein, 2012). The weather conditions, severe shaking, soil liquefaction, infrastructure collapse, downed electrical wires, and the interaction of individuals during the evacuation will all influence evacuee movement. Refer to Wood and Schmidlein (2012, 2013), Jones and others (2014), and Macpherson and others (2017, this series) for an in-depth discussion of the limitations of the LCD approach in estimating the travel times to safety.

SUMMARY

Maps accompanying this report have been completed using the best information available and are believed to be accurate; however, the report's preparation required many assumptions. In most cases the actual walking speeds proved faster than those modeled. The information presented on these maps is intended to assist state and local agencies in planning emergency evacuation and tsunami response actions. These results are not intended for land-use regulation or building-code development.

Modeling results indicate that evacuation of Japonski Island could be accomplished in about 90 minutes³, almost when the first tsunami wave (generated in the Gulf of Alaska) can arrive to Sitka Sound. Pedestrian evacuation in other parts of the city could be accomplished in less than 30 minutes, given adequate road signage to point to the direction of the most optimal routes and educational efforts about the tsunami hazard.

ACKNOWLEDGMENTS

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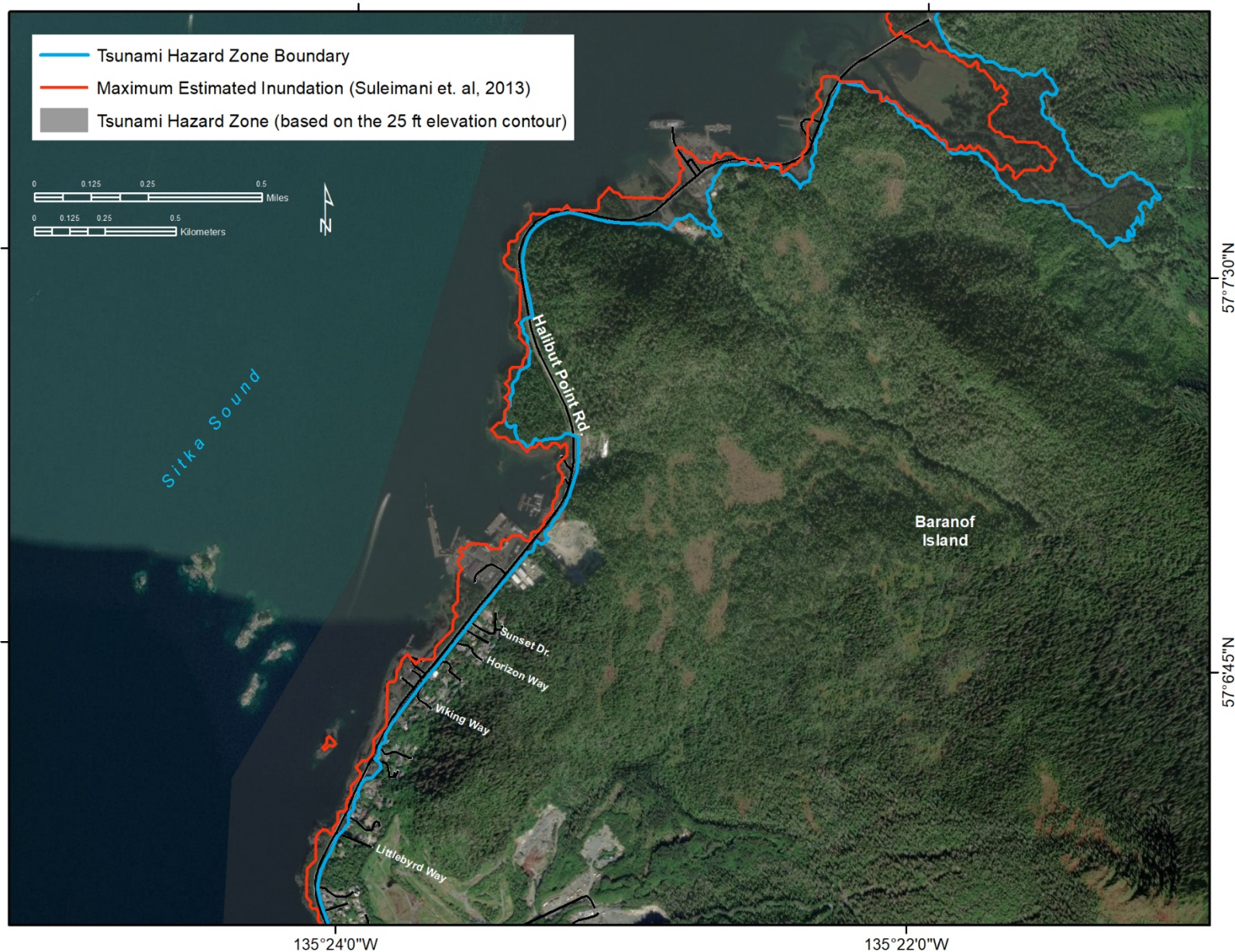
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³ Locally generated tsunami can arrive sooner than 90 minutes.

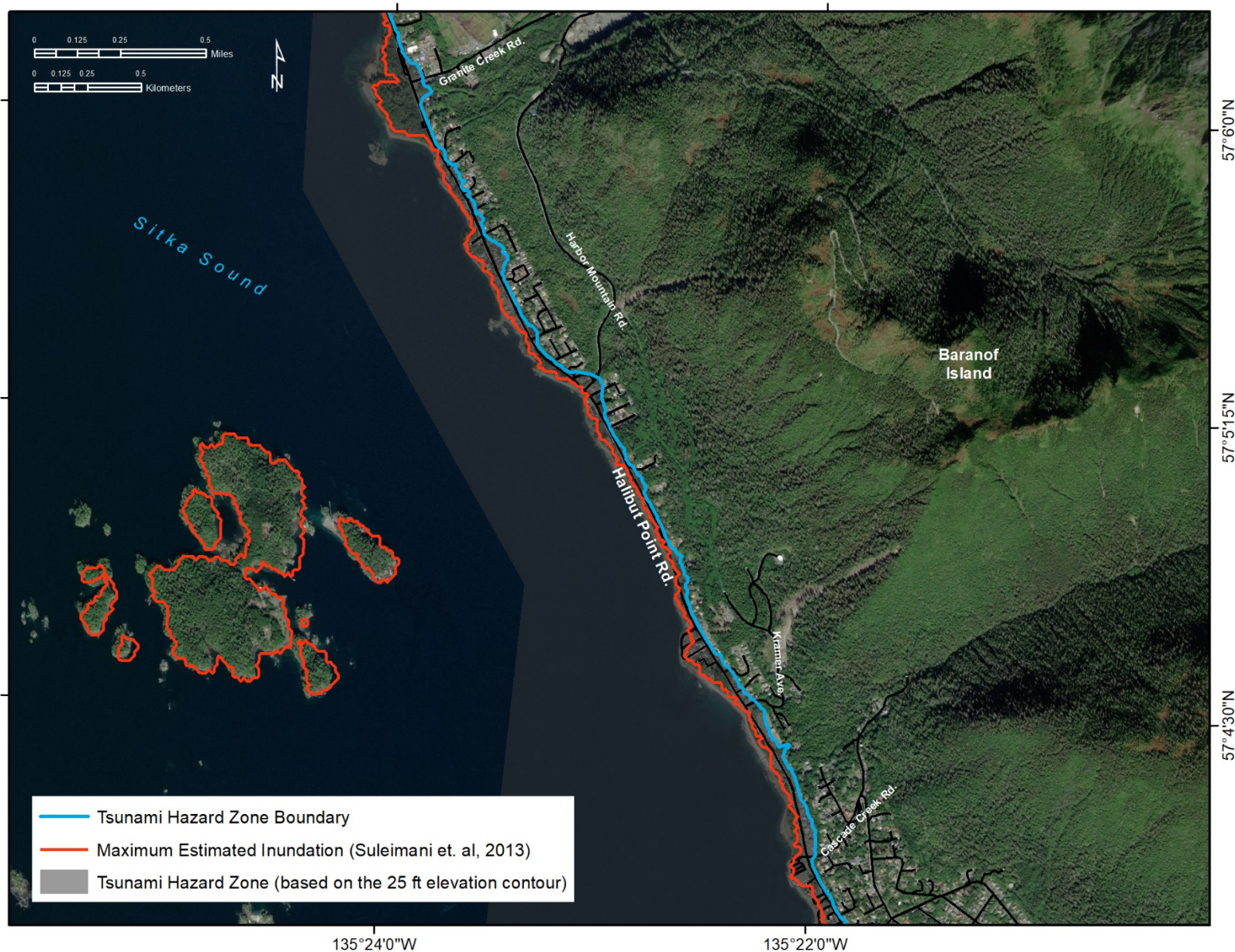
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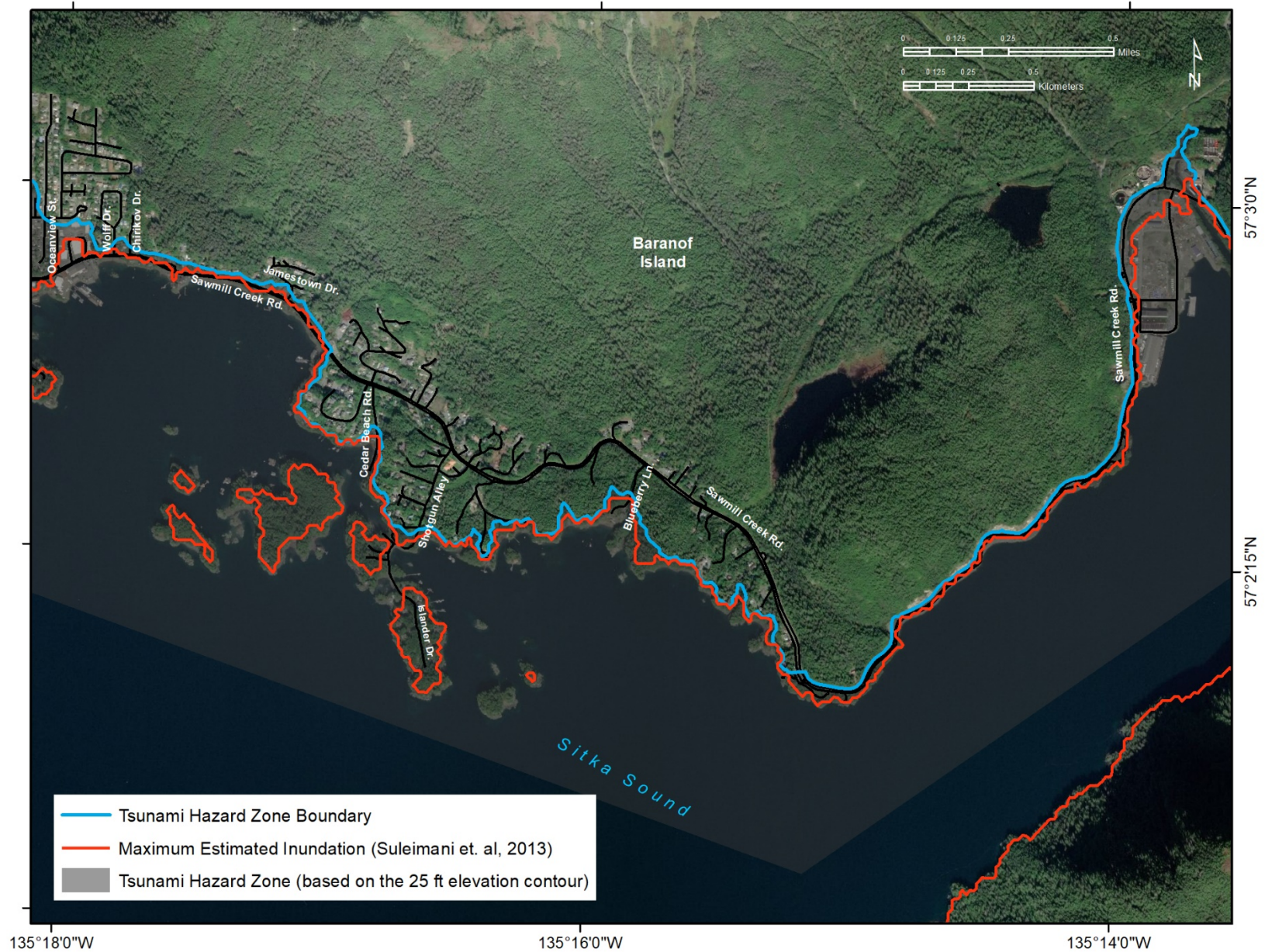
MAP SHEET 1: Modeled extent of the potential inundation and tsunami hazard zone central Sitka and Japonski Island.



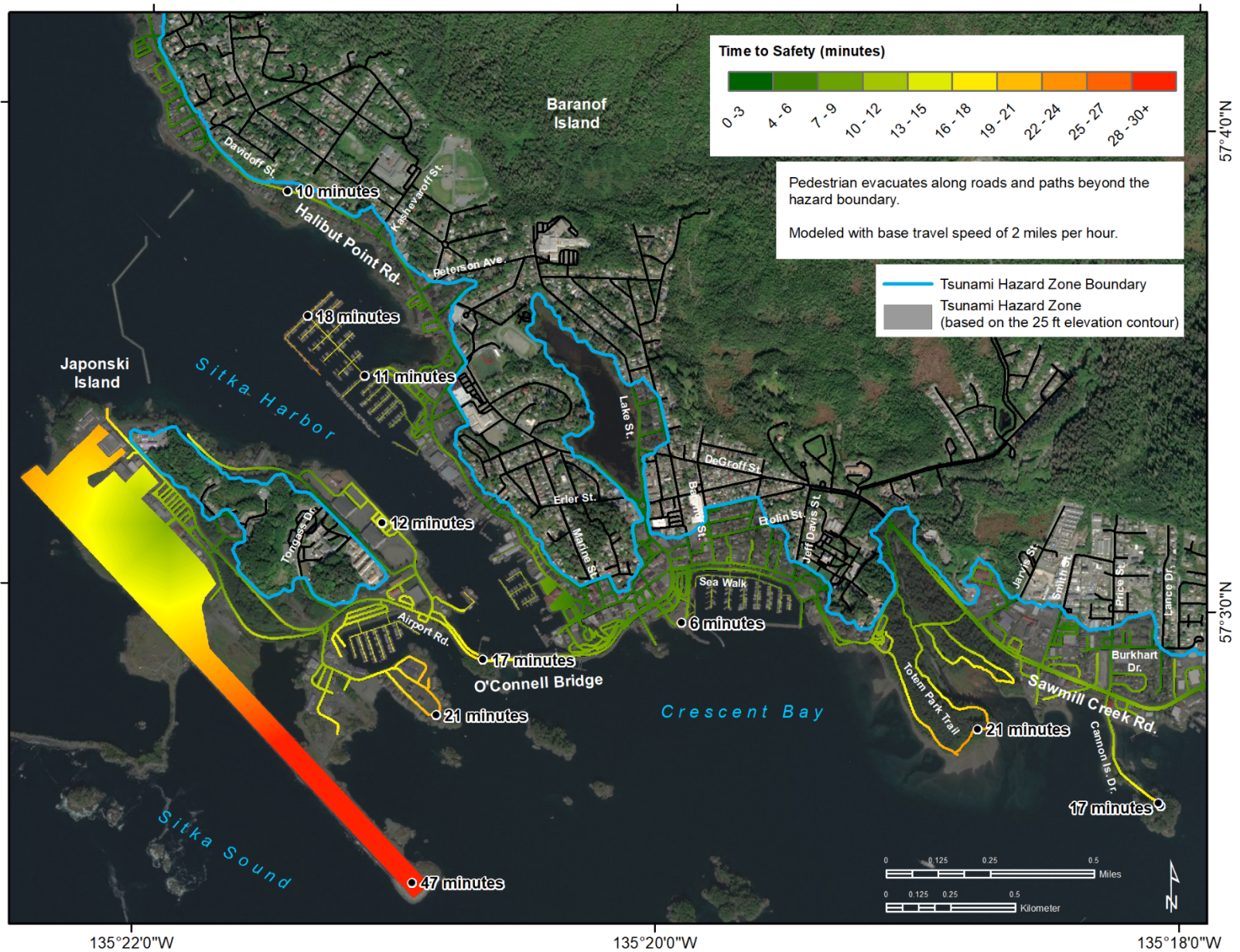
MAP SHEET 2: Modeled extent of the potential inundation and tsunami hazard zone northern Sitka.



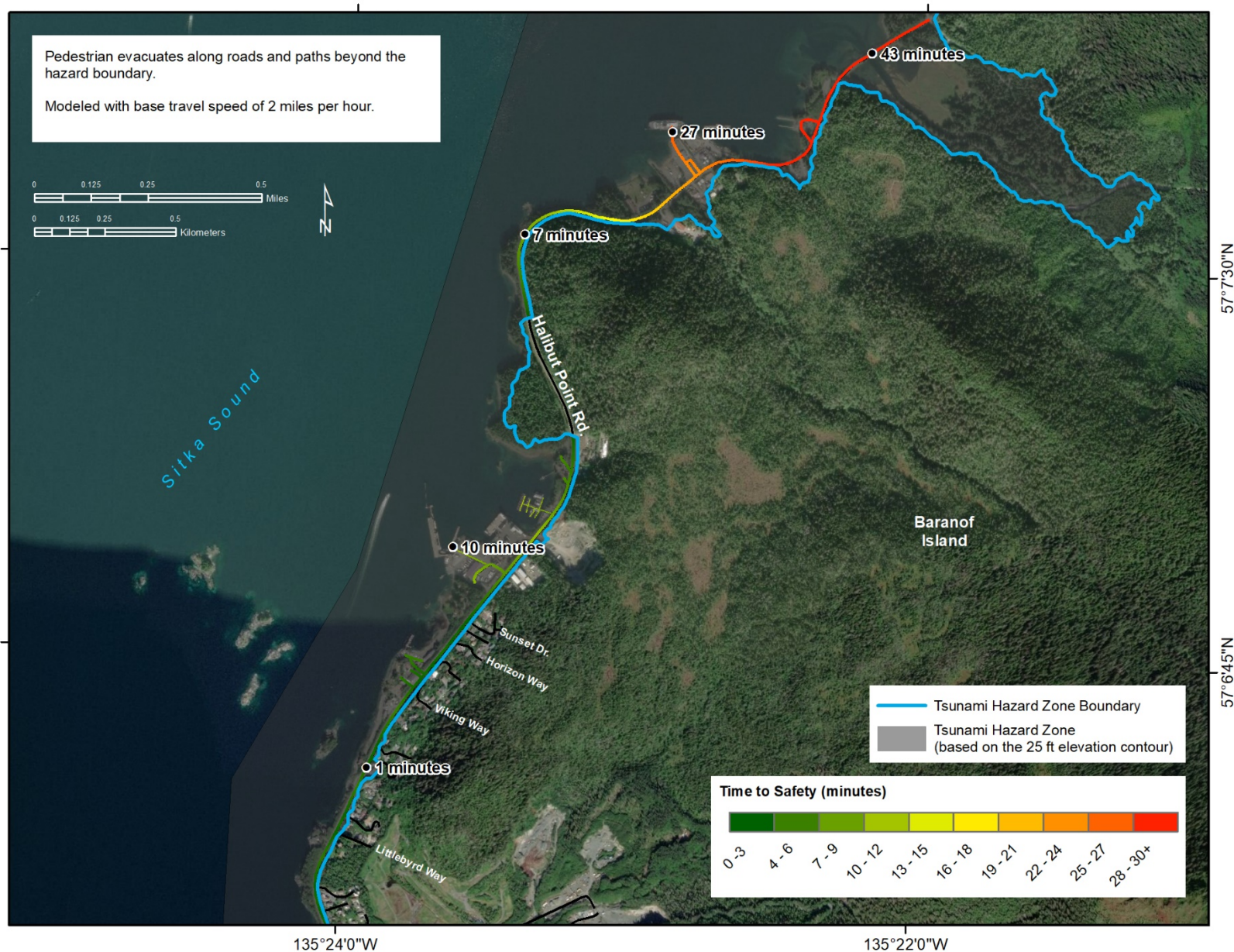
MAP SHEET 3: Modeled extent of the potential inundation and tsunami hazard zone western Sitka.



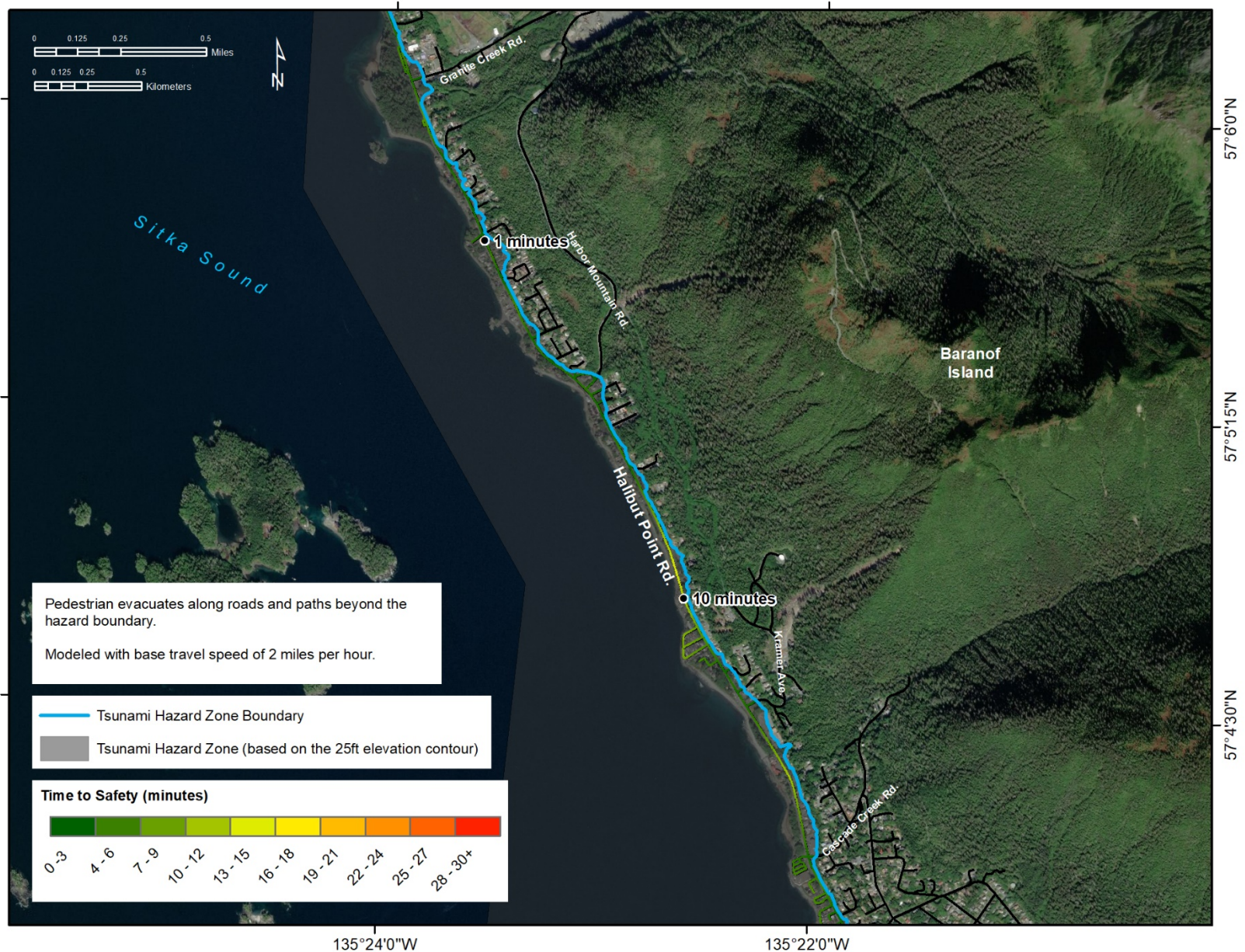
MAP SHEET 4: Modeled extent of the potential inundation and tsunami hazard zone southern Sitka.



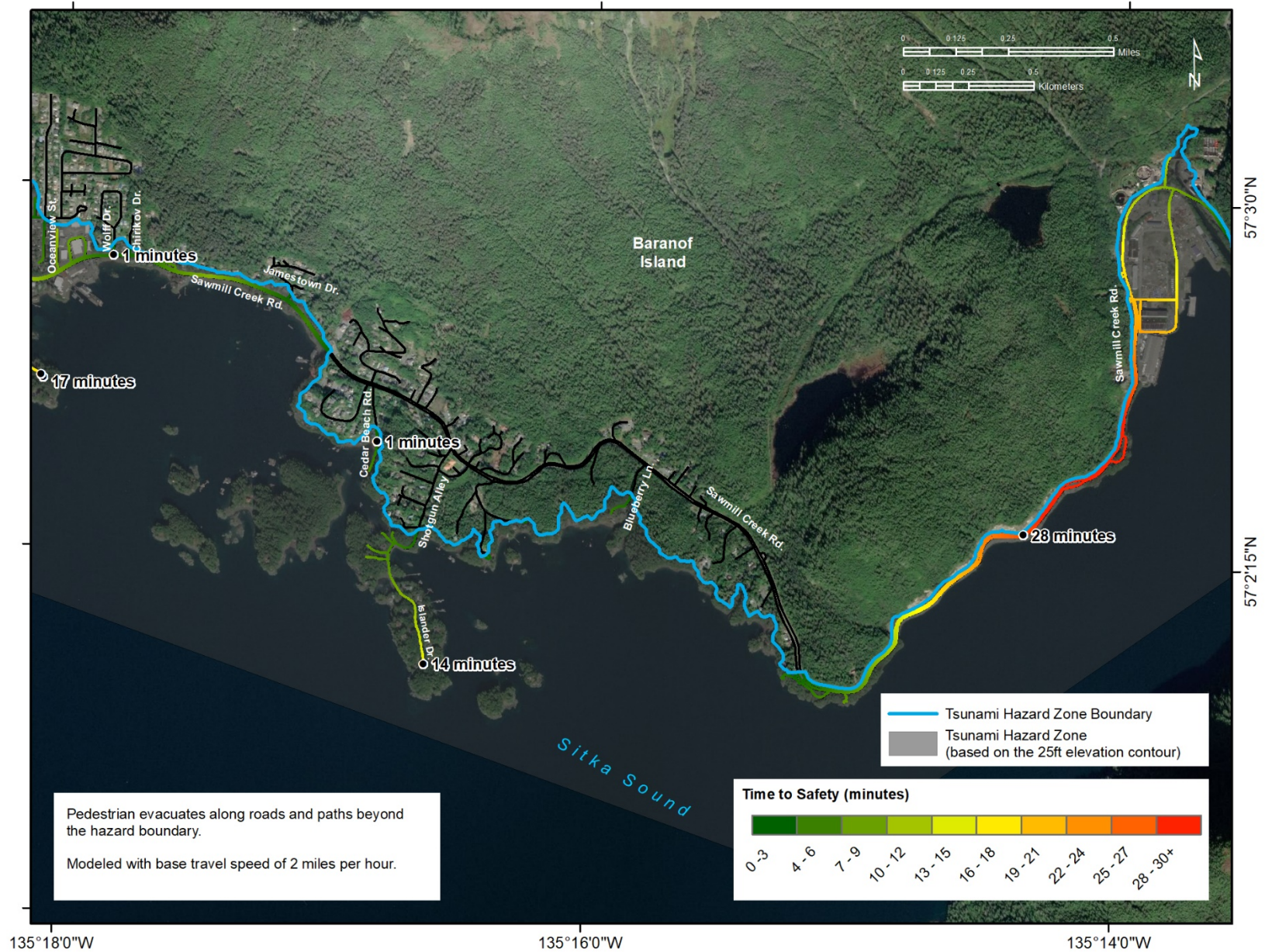
MAP SHEET 5: Travel-time map of pedestrian evacuation beyond the hazard zone boundary central Sitka and Japonski Island.



MAP SHEET 6: Travel-time map of pedestrian evacuation beyond the hazard zone boundary northern Sitka.



MAP SHEET 7: Travel-time map of pedestrian evacuation beyond the hazard zone boundary western Sitka.



MAP SHEET 8: Travel-time map of pedestrian evacuation beyond the hazard zone boundary southern Sitka.